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Abstract
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VISUALIZATION OF TRANSDUCER-PRODUCED SOUND FIELDS IN SOLIDS

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ABSTRACT

Broadband ultrasonic pulses and monochromatic ultrasonic waves are visualized in various transparent solids using a photoelastic visualization technique. Application is made to the characterization of the sound field radiated by various ultrasonic transducers operating under various excitation and coupling conditions.

INTRODUCTION

This poster paper describes several results obtained from the photoelastic visualization of piezoelectric transducer-produced sound fields in transparent elastic solids. Publication of these results will be in the 1978 IEEE Ultrasonics Symposium Proceedings.

The characterization of ultrasonic transducers can be made in two steps.[1] In one, the transduction process is characterized such that when a transducer is used as a source of ultrasound, the relationship between the electrical excitation and the acoustical output is established. A similar relationship is established for a transducer operating as a receiver. In the second step, the radiation field of the transducer is determined. While it should be possible to compute the radiated field of a transducer for which the excitation traction force and velocity are known, it has only been done in a few, limited situations. These are principally cases in which the transducer is modeled as a piston radiator, operating either in a continuous or pulsed mode with specified velocity boundary conditions between the transducer and the test medium. While this model may accurately represent the case of a transducer radiating into a liquid, it is unlikely to do so for a transducer coupled to a solid test medium. The latter is usually formulated as a traction boundary value problem and, as pointed out in a forthcoming review article,[2] aspects of this problem remain to be solved.

As reviewed in detail by Sachse and Hsu[2], the sound field of a transducer radiating into a liquid can be easily measured with microprobing transducers, spherical reflectors and optical methods, including interferometric and schlieren techniques. Most often measured are the transducer's beam or directivity patterns, its sound field amplitudes and intensities. The latter, when measured over a planar region of the sound field, can be used to reconstruct the transducer's sound field at any point in its near- or far-field.

In contrast, measurements of the sound field of a transducer coupled to a solid can only be made by indirect means. With particular specimen geometries, capacitive or electomagnetic transducers can be used to map out portions of a piezoelectric transducer's radiation field. Most often, however, optical techniques are used. These include interferometric, optical probing, schlieren and photoelastic techniques.

The implications of the foregoing are that since the sound field of a transducer radiating into a liquid can be computed, a comparison can be made between the computed and the measured sound fields and any disagreement between them can be used to indicate an anomalous behavior in the operation of the transducer. In contrast, since the analysis of a transducer coupled to a solid is incomplete, assessment of the performance of the transducer cannot be made reliably. This underscores the usefulness of field visualization measurements for these situations.

Our choice of using a photoelastic technique was based on its simplicity, its use of non-critical specimen geometries and materials (as long as they are transparent) and its potential for allowing absolute determination of various sound field quantities.

Interest in photoelastic techniques for visualizing ultrasonic fields in solids has recently redeveloped. The first application of the technique appears to have been made by Hiedeman and Hoesch[3] to visualize the stress field near a quartz transducer radiating into a glass block. The basis of the technique is that the light birefringence induced by transverse and longitudinal ultrasonic waves can be related to the refraction ellipsoid of the solid. Consequently, linearly polarized light emerges elliptically polarized when it passes through a region where an ultrasonic wave is propagating. Thus, such waves can be made visible with ordinary photoelastic techniques. The sound fields associated with longitudinal and shear waves can be studied simultaneously or separately. For optimal visualization of longitudinal waves, the polarization of the incident light should be 45° to the sound propagation direction. For shear waves, the direction of light polarization and sound propagation should be parallel. Shear waves whose particle displacements are parallel to the axis of the polariscope cannot be visualized. Application of the technique has been made to the visualization of the sound fields produced by various transducers and their interaction with various specimen geometries. Review of this past

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work is in References 2 and 4.

While there is nothing new regarding the application of the technique in this report, there are important differences with past work. In this report, a comparison between broadband, narrowband and continuous-wave excitation of a transducer coupled to a solid is explored, the temporal and field development of the radiated wave field is studied and transducer size and frequency effects are described. As in some of the recent publications, the intereaction of sound fields with artificially-produced, isolated scattering obstacles is also visualized.

TECHNIQUE

The apparatus used in our visualization experiments is equivalent to that used by Wyatt[5] and Hall[6] and is shown in Fig. 1 . It differs from theirs principally in cost. The items associated

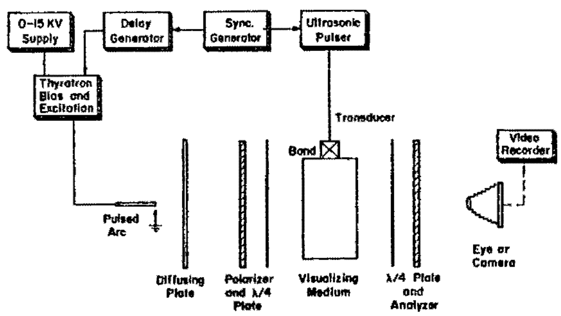

Fig. 1

with the visualization system, including its delay generator and light source, total less than $500. Secondly, while a commercially available narrowband flaw detector has been used in some of the measurements, other ultrasonic sources were also used. One was a high amplitude (-1500 volt, 40 nsec) broadband pulser which was constructed with a thyratron-based circuit. For the continuous-wave excitation, an amplitude-modulated function generator was used to obtain long r.f. bursts which were amplified with a 20 watt r.f. power amplifier. Tuned and broadband piezoelectric transducers of various sizes and frequency characteristics were coupled to blocks of glass or fused silica. The specimens were generally much larger than those used by previous investigators to allow the visualization of the long-duration r.f. bursts without interference of side-wall reflections. Critical in the visualization is a jitter-free light source which can be delay-triggered in synchronization with the ultrasonic pulse. The arc used for this purpose was a thyratron-based device reproduced from Wyatt[7]. The repetition rate of the experiments ranged from 20 to 200 Hz, allowing 1 sec exposures on ASA 200 film.

RESULTS

The propagation of a broadband ultrasonic pulse in fused silica resulting from a 12.7 mm diameter transducer is shown in Figs. 2(a) -(f) . The illuminating arc was triggered at various times relative to the excitation pulse as shown. It is clear that even initially the transducer generates not only plane waves, but also spherical waves in the solid. The secondary pulses include waves propagating with the bulk longitudinal and shear wave speeds and they appear to originate from the edge of the transducer. In the sound field of a transducer radiating into a liquid there is the obvious absence of the shear wavefront. The other pictures show that a pulse, after one reflection from a planar surface has a wavefront which appears to be spherical and there is some spreading of the pulse evident (Fig. 2(e)). After a second reflection (Fig. 2(f)), there is additional spreading and the sound field has become quite complex as a result of the reflection and mode conversion of the secondary pulses comprising the sound field. A schematic drawing of the visualized sound field prior to the occurrence of any reflections from the boundaries of the specimen is shown in Fig. 3.

Visualization of the entire sound field of a transducer appears to be most easily obtained by using long-duration r.f. bursts to excite the transducer. Figure 4 shows the sound field of broadband transducer, 6.35 mm in diameter, under a 2 MHz long-duration burst excitation. The transducer's near-to-far-field transition region can be identified. The sound field of a 6.35 mm diameter broadband transducer with long-duration r.f. burst excitation of 500 kHz and 4 MHz center frequency is shown, respectively in Figs. 5(a) and (b) . Clearly evident is the spherical nature of the sound field at the higher frequency. The effect of transducer size is shown in Figs. 6(a) and (b) in which the excitation was an identical 1 MHz r.f. burst, but (a) and (b) are respectively the sound field of a 6.35 mm and a 25.4 mm diameter transducer. Finally, Fig. 7 shows a comparison of the sound fields produced by 24° angle beam transducers under broadband, narrowband and long-duration r.f. burst excitation. Both the longitudinal and the shear wave sound fields are visible. The expected wave propagation directions are shown in (a), while (b) and (c) show the sound field generated by a broadband and a narrowband transducer under shock excitation. In (d) the narrowband transducer is excited with a 3.2 MHz, 12 μsec long r.f. burst.

The photoelastic visualization technique was used to investigate the effectiveness of the transducer coupling to the test medium. One example of the results observed is shown in Fig. 8 . In this case, a small air bubble was trapped in the coupling layer. In the resulting field, the planar wavefront in the central region of the sound field was too low in amplitude to visible photoelastically even though the two sets of spherical waves emanating from the edge of the transducer are still present. Such phenomena are clearly distinct from the sound fields present when transducers are radiating into liquids.

The use of known scattering obstacles in a test block for which the scattered sound field can be computed so as to be useful for the calibration of ultrasonic transducers is often suggested as the basis of an acceptable calibration technique. The visualization of the sound field scattered by a 1 mm diameter cylindrical side-drilled hole in glass is shown in Fig. 9 . Other scattering obstacles, such as crack-like slots, have also been studied. In each case, the complexities of the scattered sound field resulting from mode conversion and diffraction effects are apparent and thus must be accounted for when considering any obstacle as the basis of a transducer calibration block.

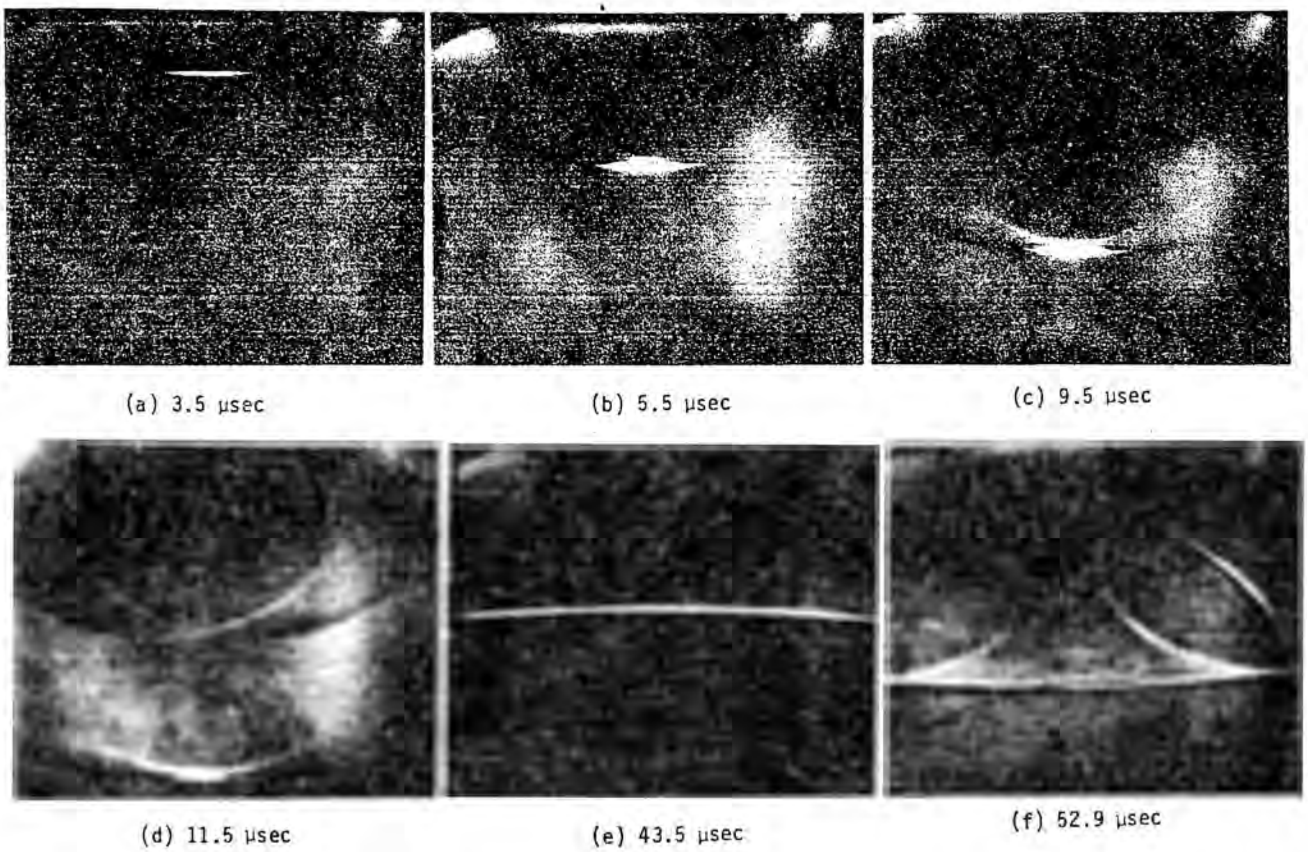

Fig. 2 - Photoelastic visualization of a broadband ultrasonic pulse at various locations in a large fused silica block.

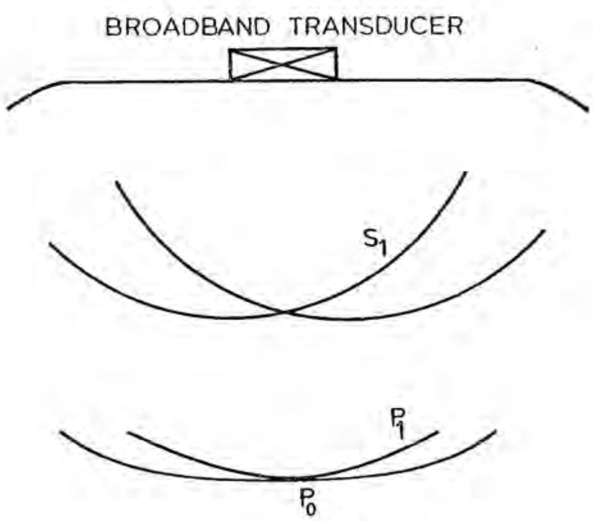

Fig. 3 Wavefronts appearing in Figure 2(c)

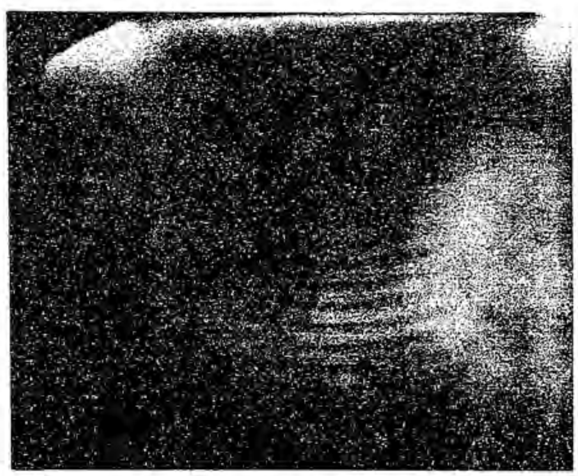

Fig. 4 Acoustic field in fused silica of a 6.35 mm dia. transducer excited at 2 MHz.

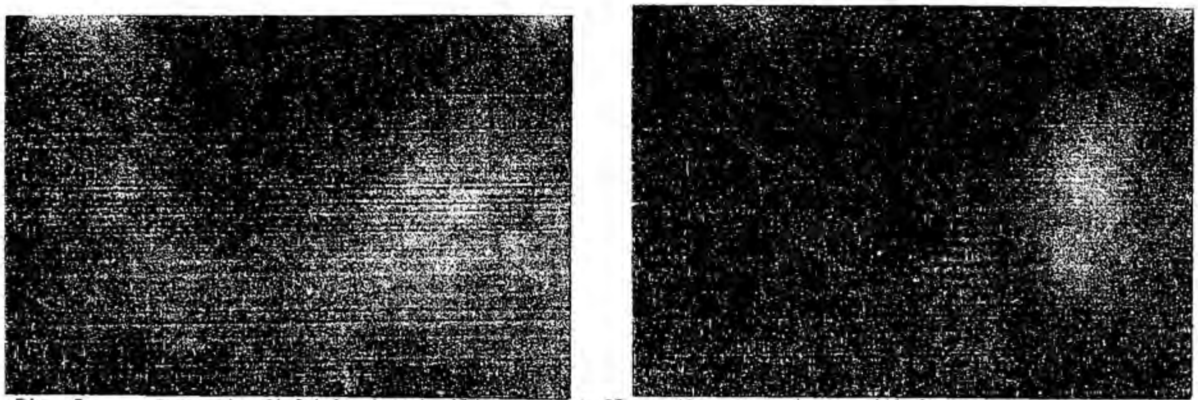

Fig. 5 Acoustic field in fused silica of a 6.35 mm dia. transducer with long-duration r.f. burst excitation. (a) 500 kHz; (b) 4 MHz.

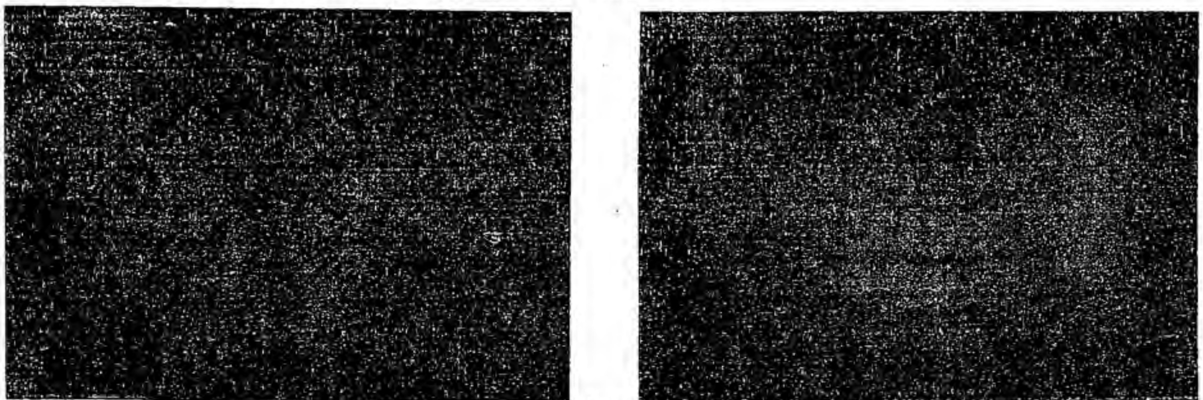

Fig. 6 Visualization of the effect of transducer size on the radiated field. 1 MHz long-duration burst excitation. (a) 6.35 mm dia.; (b) 25.4 mm dia.

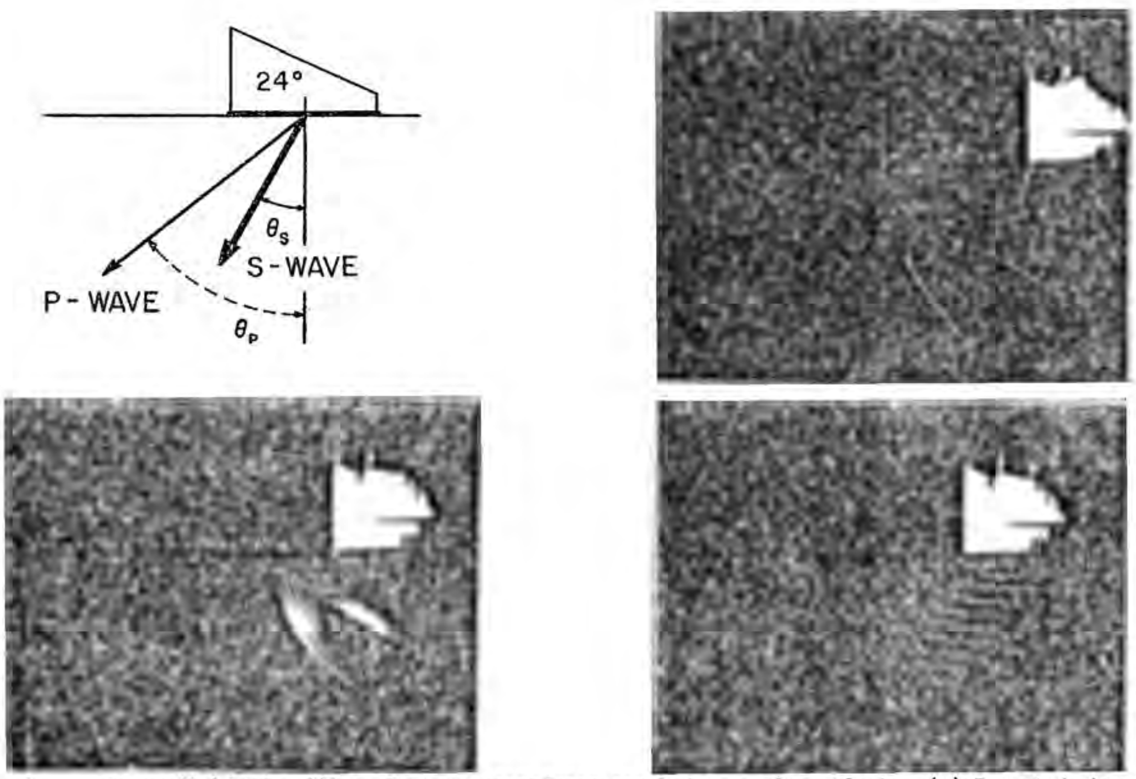

Fig. 7 Sound field of a 24° angle beam transducer coupled to a glass block. (a) Expected shear and longitudinal wave propagation directions; (b) Broadband pulse; (c) Narrowband pulse and (d) 3.2 MHz, 12 μsec long burst. (b) and (c) different transducers, same source; (c) and (d) same transducer, different sources.

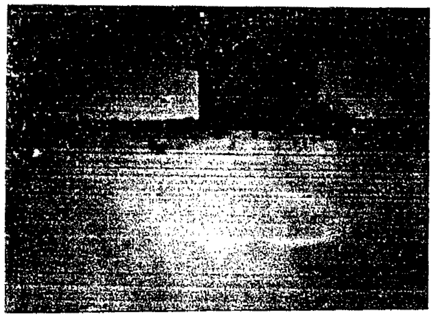

Fig. 8 Sound field of a transducer operating through a bad bond. (Air bubbles in coupling layer)

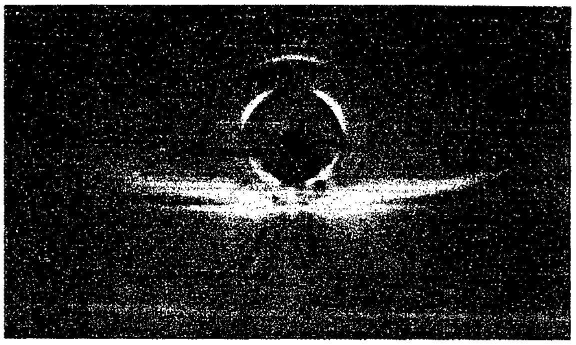

Fig. 9 Scattering by a 1 mm side-drilled hole.

CONCLUSIONS

The effectiveness of the photoelastic technique to visualize various transducer-produced sound fields in transparent solids has been shown. The technique, which is simple to use, has been applied to observe features of transducer sound fields in solids which differ from those of a transducer radiating into a liquid. While only qualitative results have been shown here, it is possible to quantify the technique. Recent advances in signal processing may play a role in the analysis of photoelastically obtained transducer field patterns. By digitizing the field either directly from the polariscope or from films, the image of the field can be processed to yield the absolute principal stress differences associated with a transducer's sound field.

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